CHAPTER 3

GROUND-WAVE PROPAGATION

3.1 INTRODUCTION

Any discussion of Navy HF radio communications would be incomplete without some consideration of ground-wave propagation. The lower frequencies (2 to 4 MHz) of the HF band are used extensively in the ground-wave mode for local area broadcasts and close-in (from line of sight out to approximately 300 miles) ship-to-shore communications to fill the skip-distance gaps left by ionospheric propagation. The low end of the HF band is used for this purpose, in spite of high attenuation at these frequencies, primarily because efficient transmitting antennas for frequencies below the HF band are too large for shipboard installation.

A detailed discussion of ground-wave propagation is more appropriate for a handbook concerned with frequencies above and below the HF band, and, since handbooks covering communication systems in other parts of the spectrum are planned for future publication, the discussion of ground-wave propagation here will be brief.

3.2 DEFINITION OF GROUND-WAVE PROPAGATION

Ground-wave propagation is defined in various ways in the technical literature. For the discussion here the term "ground-wave" is defined as a radio wave traveling over the surface of the earth without dependence on reflection from either the ionosphere or the ground. This definition is not strictly accurate according to some authorities, but it is a common concept and, at the low end of the HF band, the inaccuracy is of no practical consequence.

3.3 MECHANICS OF GROUND-WAVE PROPAGATION

The physical mechanics of ground-wave progation are less complicated than those of sky-wave propagation. Ground waves are propagated within the troposphere (the first 7 to 10 miles above the earth's surface), there are fewer variables involved, and these are not subject to such random behavior and extreme excursions as is the case for sky-wave transmission.

Refraction in the troposphere and diffraction of energy toward the earth's surface account for the tendency of a ground wave to follow the contour of the earth's surface and thereby achieve transmission distances beyond the line of sight. In the troposphere, the index of refraction normally decreases with height so that a ground wave is bent, or tilted, toward the earth in a manner similar to the refraction of radio waves in the ionosphere. Additional tilting of the wave front is caused by diffraction of energy downward from upper portions of the wave to partially replenish energy absorbed by the earth.

The earth's surface exhibits electrical characteristics similar to a resistance shunted by a capacitive reactance. Since a horizontal electric vector represents a difference of potential directly across the earth's impedance, a horizontal electric field tends to be short-circuited by the earth. As a consequence, a horizontal electric field is attenuated much more rapidly than a vertical one. Therefore, vertical polarization must be used to obtain transmission distances of more than a few miles.

As a ground wave travels over the surface of the earth, energy is lost as a result of induced currents flowing through the earth's resistance. This ground loss, which increases with increasing frequency, depends upon the conductivity and dielectric constant of the surface of the earth. The effect of these ground constants is frequency dependent, and, moreover, the apparent thickness of the surface of the earth is also frequency dependent. At sufficiently low frequencies the earth appears to be predominently resistive and conductivity is the dominant factor; at sufficiently high frequencies the earth appears to be primarily a capacitive reactance and the effect of the dielectric constant is dominant. The surface depth contributing to these effects increases with decreasing frequency. At the frequencies of interest here, 2 to 4 MHz, conductivity is the dominant factor, especially over sea water, with the dielectric constant exerting some influence over land. In any case, sea water is the best "ground" because its conductivity and dielectric constant are much higher than any to be found in a land mass.

Typical values of ground constants normally associated with various types of terrain are given in table 4-4, but classifying ground as poor, good or sea water is adequate for practical purposes. The ground constants chosen to represent good and poor ground vary slightly in the literature but not enough to affect field strength calculations significantly. The ground-wave propagation curves included in this chapter are those for commonly used values, namely:

	Conductivity (mho/meter)	Dielectric Constant
Sea water	5	80
Good ground	10^{-2}	15
Poor ground	10^{-3}	5

Figure 3-1 shows the manner in which polarization and the three types of ground affect field intensities.

3.4 FIELD INTENSITY CALCULATIONS

Ground-wave propagation curves have been derived by rigorous mathematical analysis of the problem and are available for predicting field intensity as a function of frequency and of distance from the transmitter. Figures 3-2, 3-3 and 3-4 are sets of such curves for the three types of terrain defined in the preceding section. The curves are referred to an unattenuated field intensity of 186.3/D millivolts per meter, where D is the distance in miles from the transmitter. That is, the inverse distance line on the set of curves represents the field intensity that would exist, relative to 186.3 mV/m at one mile, if there were no losses other than spreading of the wavefront with distance. The reference field, 186. 3 mV/m at one mile (300 mV/m at one kilometer), corresponds to the case of an electrically short, lossless, vertical antenna, radiating 1 kW, placed on the surface of a perfectly conducting earth. This is an elementary monopole with a gain of 4. 76 dB relative to an isotropic antenna. The curves are for a smooth homogeneous earth, no allowance being made for the effects of hills, cities, vegetation, and the like.

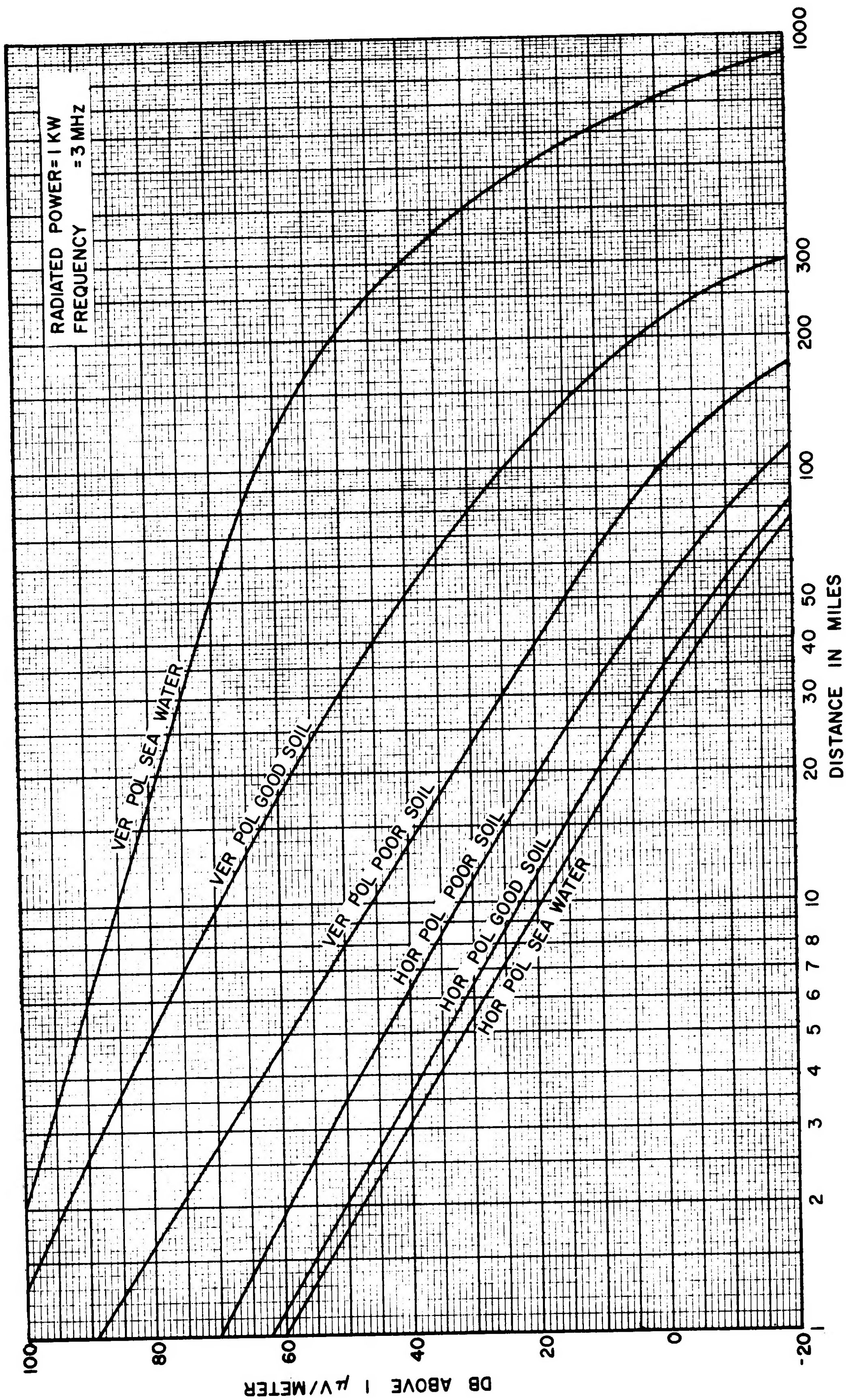

Figure 3-1. Elementary Dipole Propagation, Vertical and Horizontal Polarization

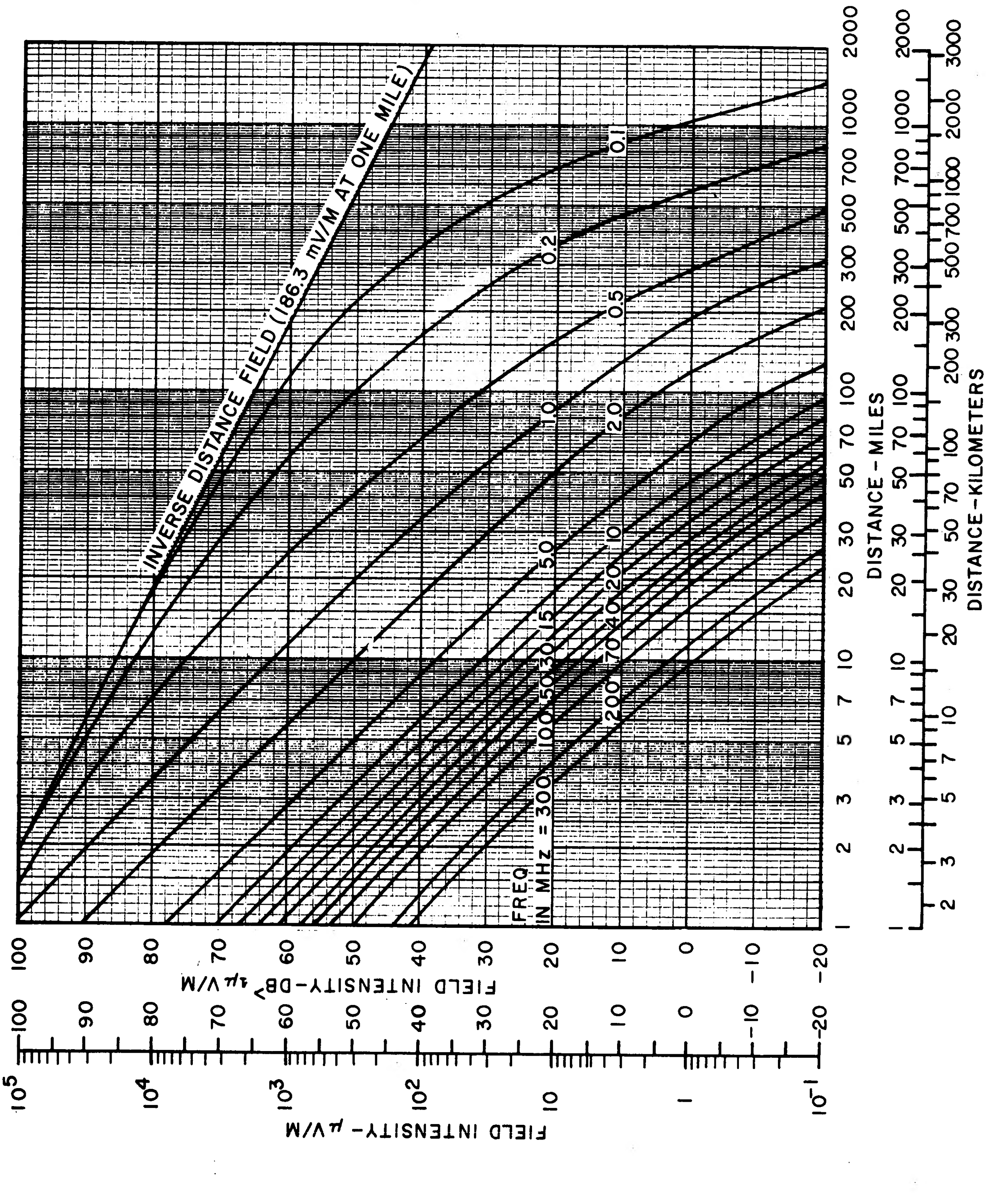

Figure 3-2. Ground-Wave Propagation Curves, "Poor Ground"

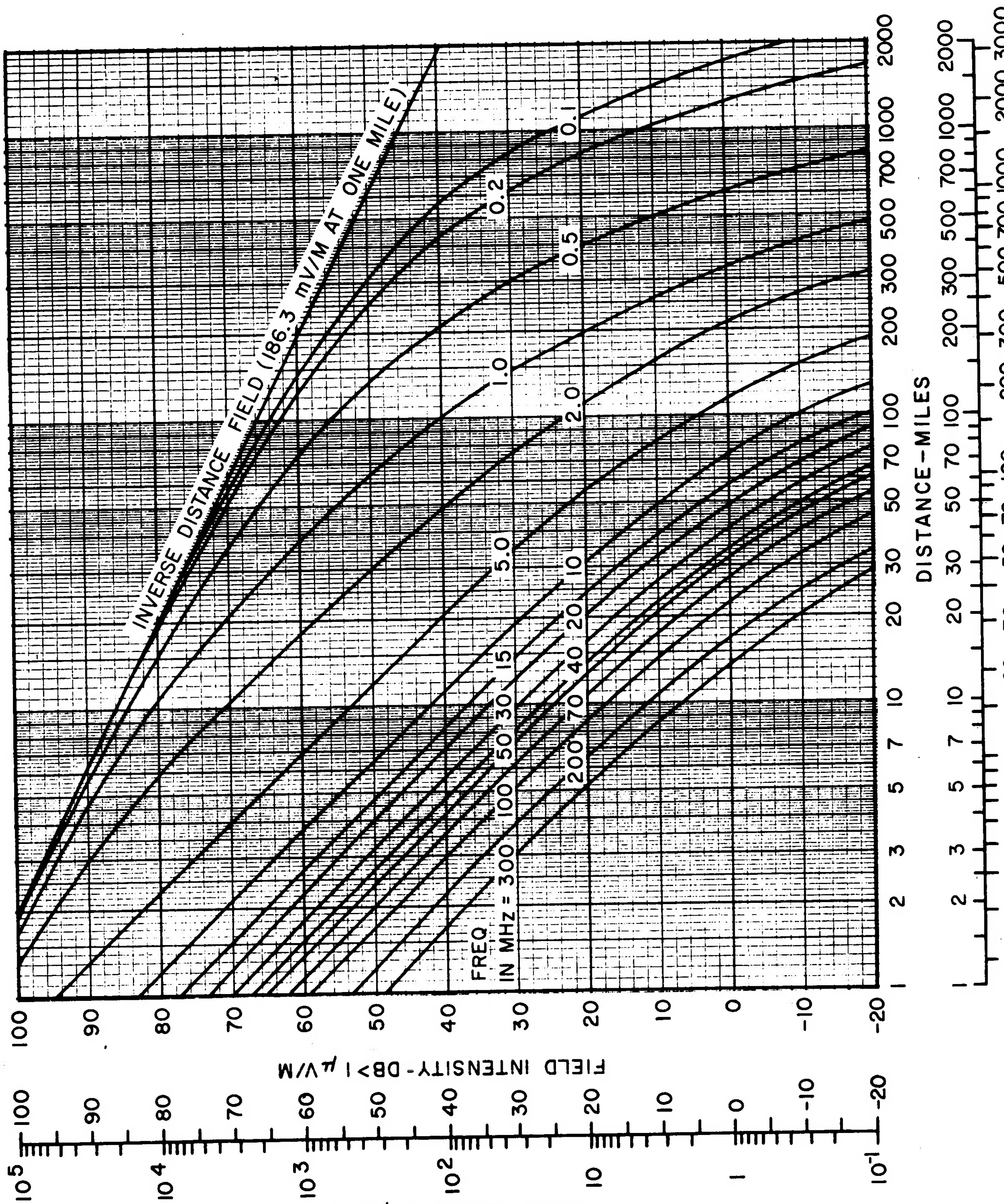

Figure 3-3. Ground-Wave Propagation Curves, "Good Ground".

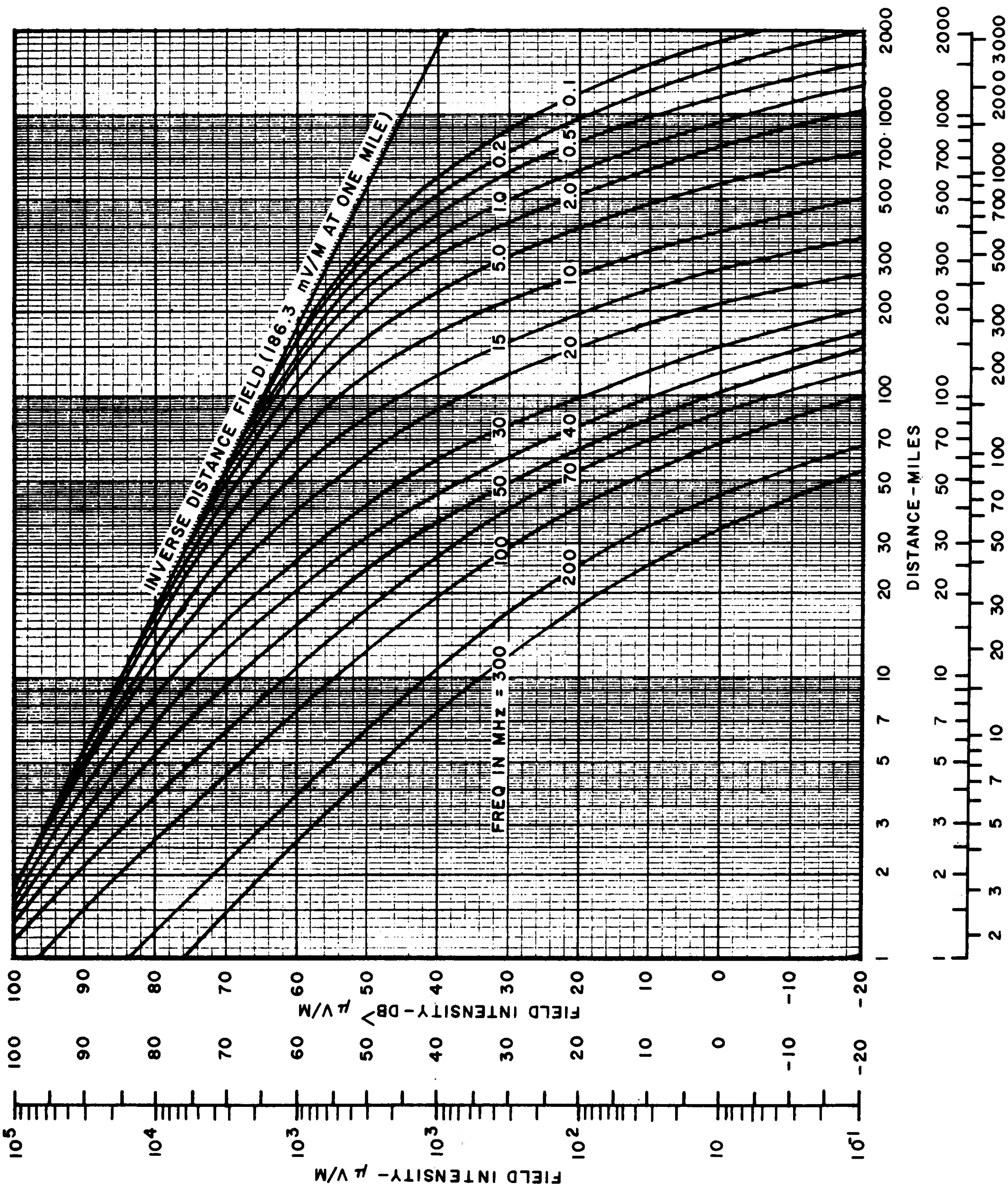

Figure 3-4. Ground-Wave Propagation Curves, Sea Water

3.4.1 Sample Field Intensity Calculations

The propagation curves can be used to predict ground-wave field intensities for conditions other than those for which they were drawn. The general procedure is to find the field intensity at the frequency and distance of interest, using the set of curves for the type of ground in the path, and then to correct this field intensity for the conditions that differ from those specified for the curves. To illustrate the procedure, two examples will be considered: one for the case where the terrain for the entire path can be considered as one type, i.e., either poor ground, good ground or sea water; and one for a mixed path where part of the distance is over land and part over sea water. Corrections for antenna height above ground are not considered since vertical HF antennas for surface communications are on or very near the ground.

a. Example 1 — Transmission path over good ground. Assume that the field intensity is required for the following conditions:

Transmission distance	100 miles
Operating frequency	2 MHz
Transmitting antenna gain	2 dB (above elementary monopole)
Antenna input power	2 kW
Type of intervening ground	Good

Figure 3-3 shows the field intensity at 100 miles on the 2 MHz curve as being 23 dB above 1 μV/m. This field intensity is corrected for the example conditions as follows:

Reference field intensity	23 dB
Antenna Gain	2 dB
Antenna input power (dB relative to 1 kW)	3 dB
Expected field intensity (dB above 1 μV/m)	28 dB

The conversion scale on the chart can be used to convert the result to approximately 25 μV/m.

b. Example 2 — Transmission over a mixed path. Two sets of curves (figures 3-2 and 3-4) are used for this case. To illustrate, assume the following conditions:

Transmission distance	100 miles
Operating frequency	2 MHz
Transmitting antenna gain	2 dB (above elementary monopole)
Antenna input power	2 kW
Type of ground	
First 20 miles from transmitter	Poor
Next 80 miles from transmitter	Sea water

The poor ground curve is used for the first 20 miles and then the sea water curve is used for 80 miles beyond the distance at which the sea water curve has the same field intensity as the poor ground curve has at 20 miles. From the set of curves for poor ground, figure 3-2, the field intensity at 20 miles on the 2 MHz curve is read as 37 dB above 1 μV/m. This field intensity is then used to enter the sea water curves, figure 3-4. The 37-dB field intensity intersects the 2-MHz curve at a distance of 340 miles. Then the field intensity for the mixed path is obtained by reading the value on the 2-MHz curve at a distance 80 miles greater, 420 miles. The result is 30 dB above 1 μV/m. The corrections for differences from the reference conditions are the same as for example 1 where the antenna gain and input power corrections amounted to 5 dB. Therefore, the field intensity to be expected at 100 miles is 35 dB above 1 μV/m, or 56 microvolts per meter.

3.5 POWER REQUIREMENT PREDICTIONS

Calculations of signal field intensities for a given frequency and distance from a transmitter are of little value unless the signal strengths are compared to the noise level likely to prevail at the receiving site. Moreover, there are occasions when, rather than to find the field intensity at a given location, it is more useful to determine the effective radiated power required to produce an acceptable signal-to-noise ratio at that location. In this case, instead of proceeding from a given transmitted power to a predicted signal field intensity, as in the previous examples, one must work backwards from a required signal-to-noise ratio to the required radiated power. To illustrate the procedure, assume that a signal-to-noise ratio of 29 dB is required 300 miles at sea from a transmitting station close to the shore line. Further, assume that the operating frequency is 3 MHz and the signal bandwidth is 3 kHz.

The noise level can be estimated in the manner described in paragraph 2.7.2e of chapter 2 using figures A-22, A-23 and A-24. Assume for this example that the noise estimate for a selected time and season, say 0400-0800 in summer, turns out to be −142 dBW for a 1-Hz bandwidth. This noise power level cannot be compared directly to signal levels read from the ground-wave propagation curves, since, for these curves, signal strength is expressed in terms of field intensity (μV/m). The nomogram of figure 3-5, extracted from CCIR Report 322, must be used to convert this noise power into noise field intensity. In figure 3-5, the noise factor F_a is defined by:

$$F_a = 10 \log \frac{p_n}{kT_o b} \qquad (3\text{-}1)$$

where

p_n = noise power received from sources external to the antenna (watts)

k = Boltzman's constant = 1.38×10^{-23} Joules per degree Kelvin

T_o = reference temperature, 288° K

b = effective noise bandwidth (H_z)

If b is specified as 1 Hz, which must be done to match the bandwidth for the noise estimate above, 10 log $kT_o b$ is equivalent to 204 dB below one watt, or −204 dBW.

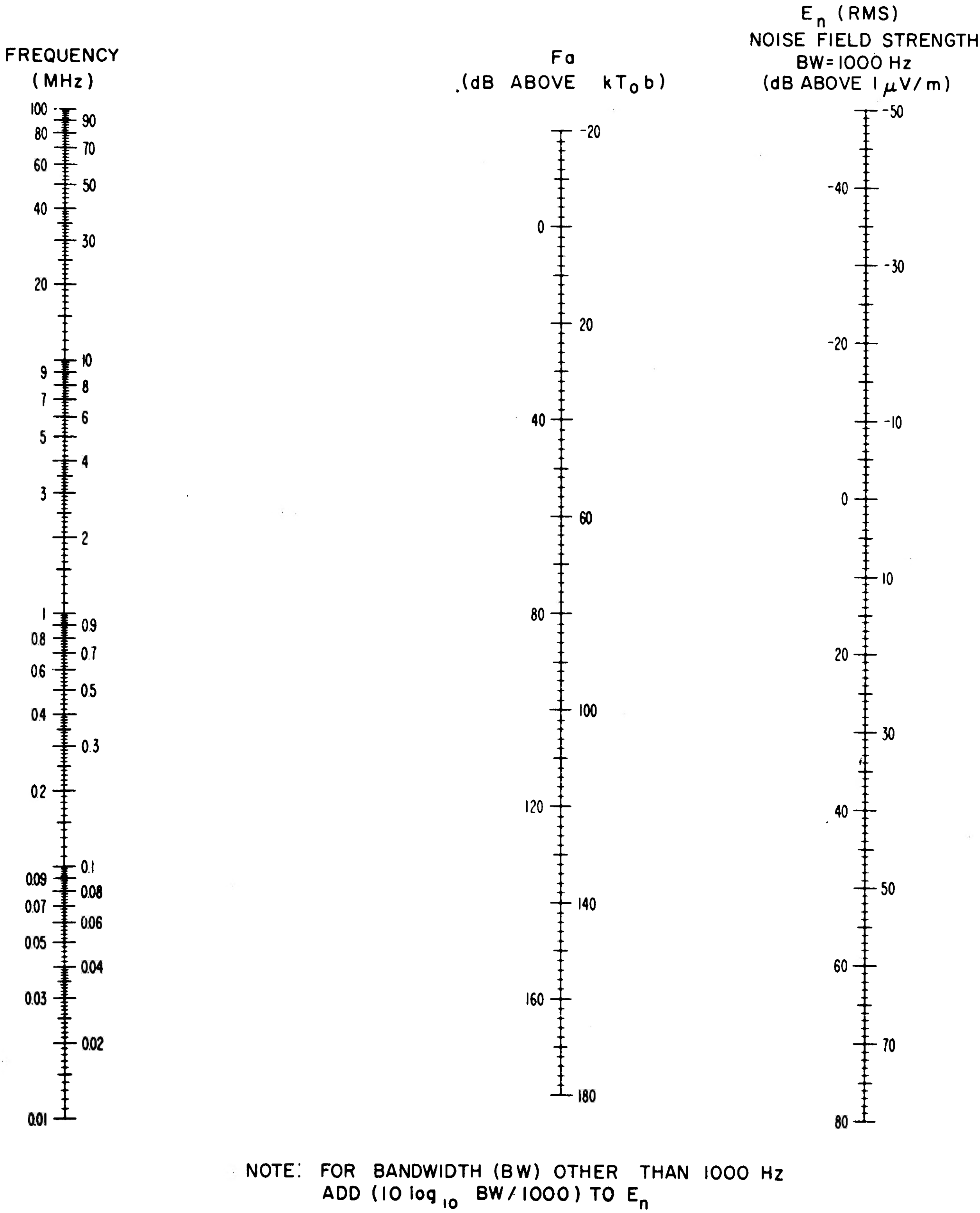

Figure 3-5. Nomogram for Transforming Noise Power to Noise Field Strength

Therefore, the noise level, −142 dBW (1-Hz bandwidth), is equivalent to 62 dB above kT_0b, and the noise factor F_a is 62.

The nomogram, figure 3-5, can now be entered with the frequency, 3 MHz, and $F_a = 62$ to find the noise field strength E_n, in dB relative to 1 μV/m for a 1-kHz bandwidth. The result, $E_n = 6$ dB, is the noise field strength for a 1000-Hz bandwidth and must be adjusted to match the signal bandwidth of 3 kHz. This is done by following the instructions in the note on the nomogram, and in this case the correction is 10 log 3 = 4.8 dB. This correction factor is added to 6 dB to yield 10.8 dB above 1 μV/m for the noise field strength in the occupied bandwidth. The required signal field intensity to produce a 29-dB signal-to-noise ratio, then, is 29 + 10.8 or approximately 40 dB above 1 μV/m.

From figure 3-4, the field intensity at 300 miles for 3 MHz is 38 dB. This is the field that would be produced by a short vertical antenna radiating one kilowatt, and it is 2 dB less than the required 40 dB calculated above. The effective radiated power (ERP) to produce the desired signal field intensity is found from the relationship,

$$10 \log ERP/1000 = 2 \text{ dB},$$

from which, the ERP = 1582 or approximately 1600 watts.

Trade-offs can now be made between antenna gain and transmitter output power to select the transmitter and antenna design to produce the required effective radiated power.

In this example, the computation was made for only one time block in one season. In practice, to establish requirements for a permanent station, the procedure would be repeated for other time blocks and seasons. This would establish a broader base of data and would reveal the worst-case conditions. Moreover, some allowance, in terms of additional radiated power, normally would be made for excursions of noise power above the median valves given in the predictions.